Validation of Geant4 Hadronic Models and Customizing Physics Lists for NuMI-X Simulation

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NuMI-X meeting
10/21/2013

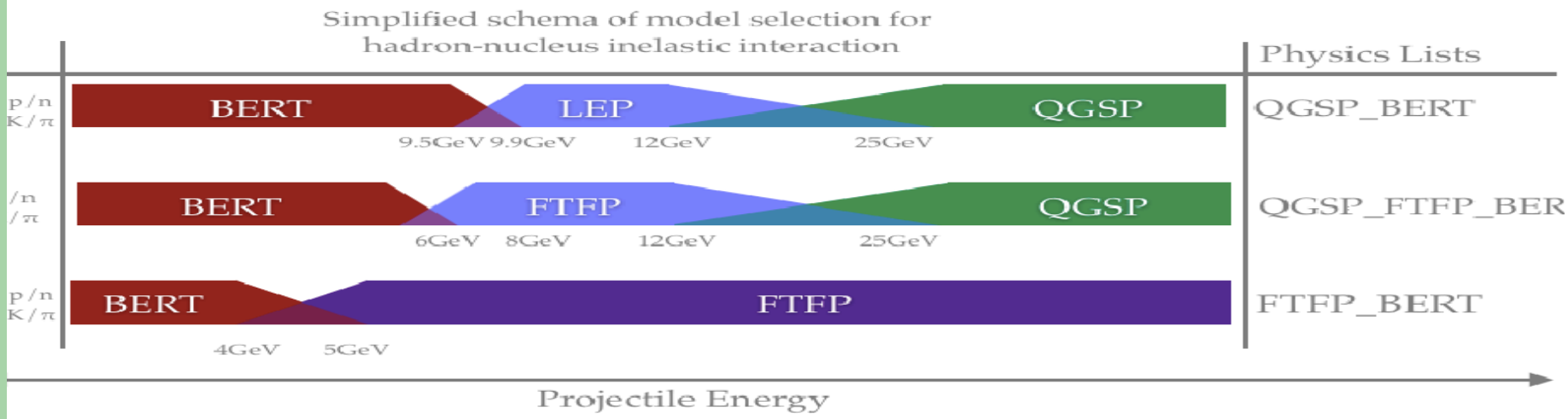
General Remarks

- We have initially discussed Geant4 high energy hadronic models in a talk at the 7/11/2013 NuMI-X meeting
- We'll reiterate on how these models are – and/or can be – tuned and benchmarked
- We'll briefly address re-interaction of secondary particles – which will mostly fall into the intermediate energy range
- We'll touch the tuning and benchmarking of Geant4 hadronic physics in the intermediate energy range
- We'll illustrate models performance via a physics list, and how a physics list can be customized for the needs of NuMI
- All results are for Geant4.9.6.p02

Hadronic Physics in Geant4 (from 7/11/2013 talk – just for ref.)

- There is NO "unified" hadronic model
- Hadronic models are valid (or better fit) for combinations
  particle type – energy (- target material)
- Need to choose a set of hadronic models to cover all possible interactions – Physics List (what a user sees)
- The choice is NOT a "black box" but depends on use-case:
  - The particles in simulation
  - The energy scale
  - The compromise between accuracy and CPU
- Collection of ready-to-use physics lists exists
- Users can also tailor any of those, or write their own

Geant4 Physics List Composition - Overlap of Models



NuMI-X: 1st interaction is always done by a single HE model
Further interactions: a mix of everything…

Included in this study – experimental/private NuBeam Phys.List:

- Similar to FTFP_BERT
- "Custom" proton builder (more later)
- BERT/FTF overlap at 7-10GeV

High Energy Hadronic Physics Models in Geant4

- FTF (from 3GeV up) and QGS (from 15GeV up)
- Tuning and benchmarking:
  - Thin target data for p+C at 31GeV/c or 158GeV/c
  - Higher energy data are also used (but that's beyond NuMI)
  - **Other thin target data will be most welcome !!!**
  - Thick target data can NOT be used for tuning, but will be highly useful for "bulk rates" benchmarking
- Current status:
  - FTF is the best available modeling option for all hadrons in the range from ~10-100GeV
  - At >100GeV, at least for a proton projectile, QGS is likely to be a better model, especially if properly outfitted

High Energy Hadronic Physics Models in Geant4 (cont.)

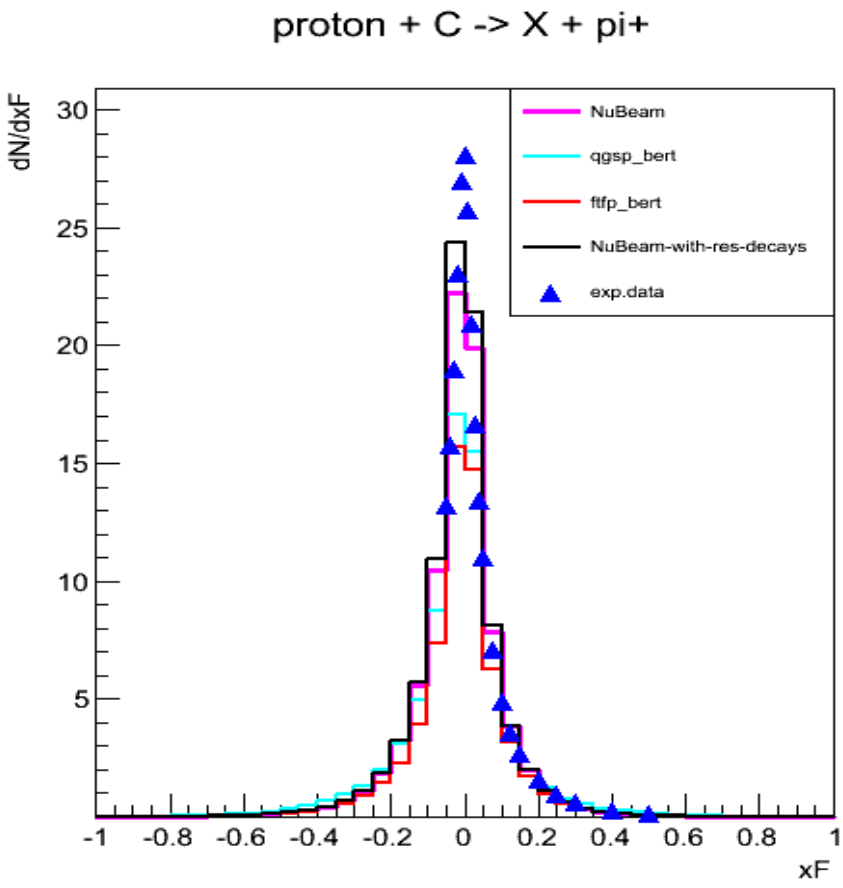
- Both FTF and QGS serve as basis to "HE generator":
  - String model itself (gives name to physics list)
  - String Fragmentation
    - G4LundStringFragmentation (w/FTF in standard physics lists)
      - Recently tuned to exp.data (in particular, NA49)
    - G4QGSMFragmentation (w/QGS in physics standard lists)
    - Interchangeable
  - Quasi-elastic channel (internal in FTF, CHIPS-like for QGS)
  - (Typically) Precompound at the back end

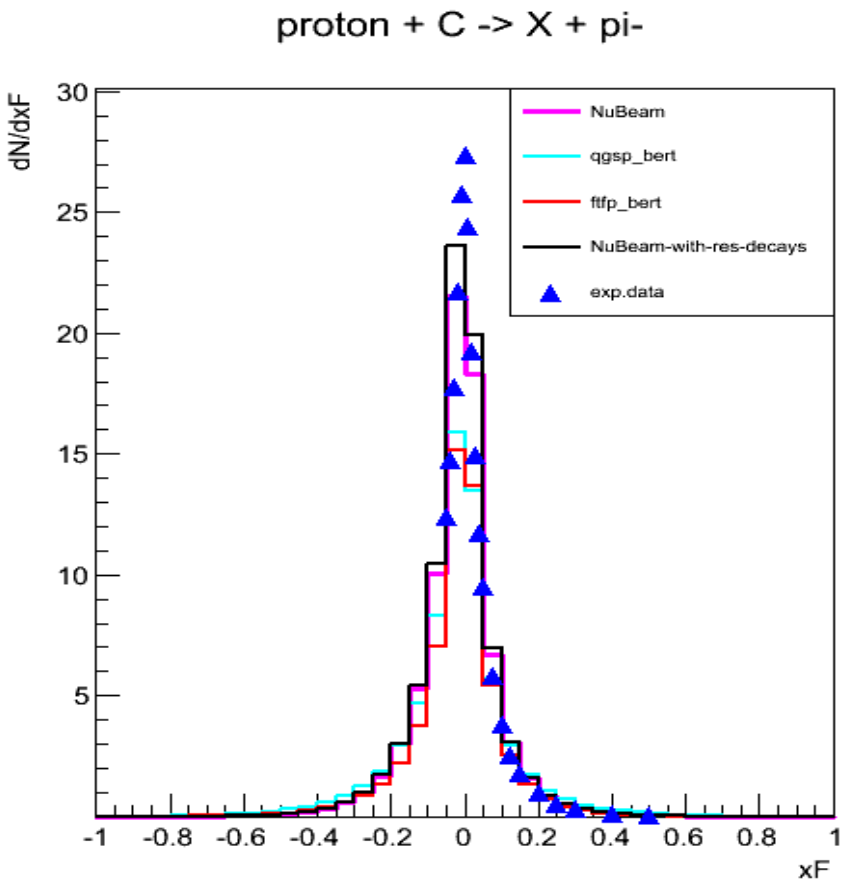
Particle Production in p+C at HE

- Pion production shapes the neutrino flux
- Pions from 1st interactions are highly important
- In practice, there'll also be pions from decays of short-lived resonances, but in the simulated 1st ProtonInelastic interactions resonances will still be undecayed (decay later)
- Re-interactions are also important
- Production of other secondary's is also important, in particular with regards to re-interaction and production of additional pions
- However, secondary's will most likely be in the several-GeV or several-tens-GeV energy range, where FTF is the best choice, so we're down to a single model

Pion Production in p+C at 158GeV/c - Different Physics Lists

Exp.data: http://spshadrons.web.cern.ch/spshadrons/ (NA49)

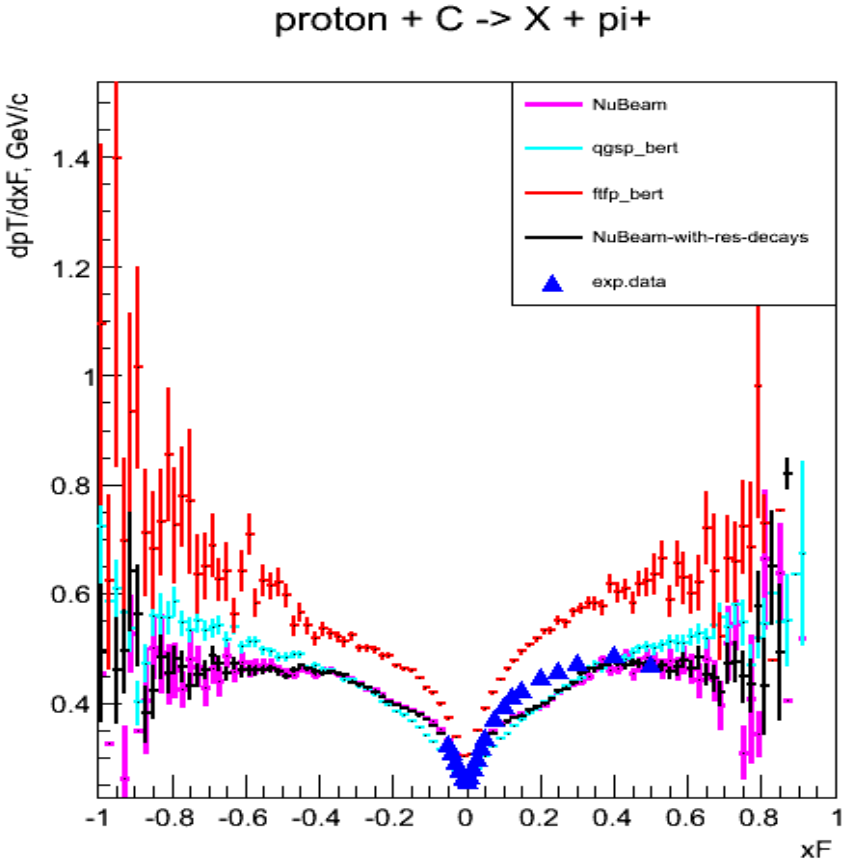


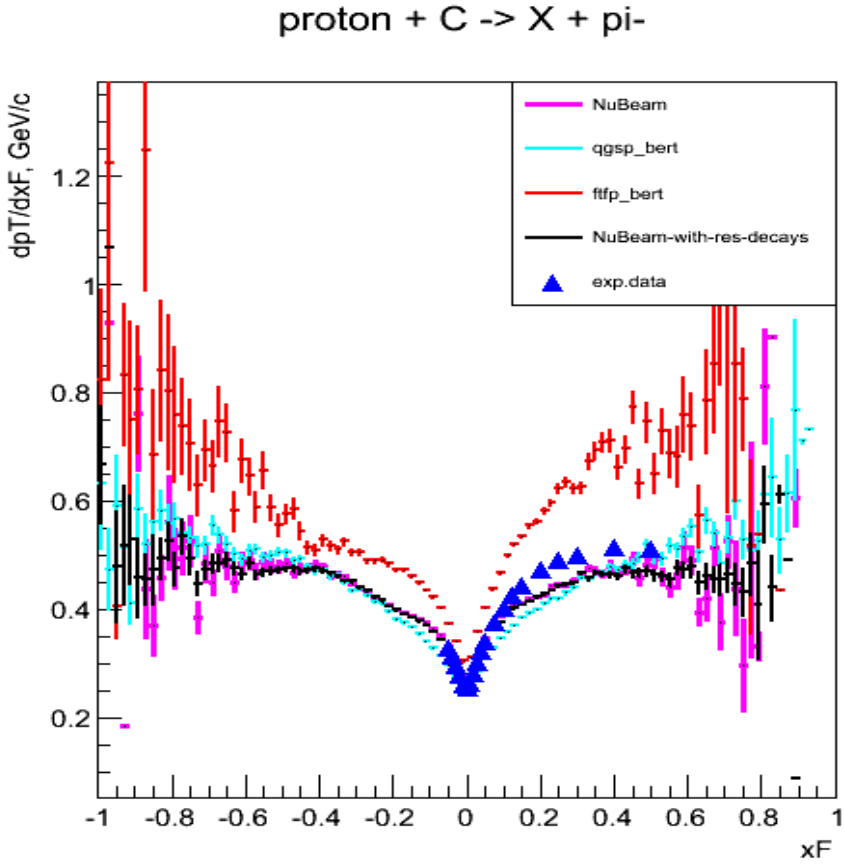


1st interaction of p on a think C target

Pion Production in p+C at 158GeV/c - Different Physics Lists (cont.)

Exp.data: http://spshadrons.web.cern.ch/spshadrons/ (NA49)

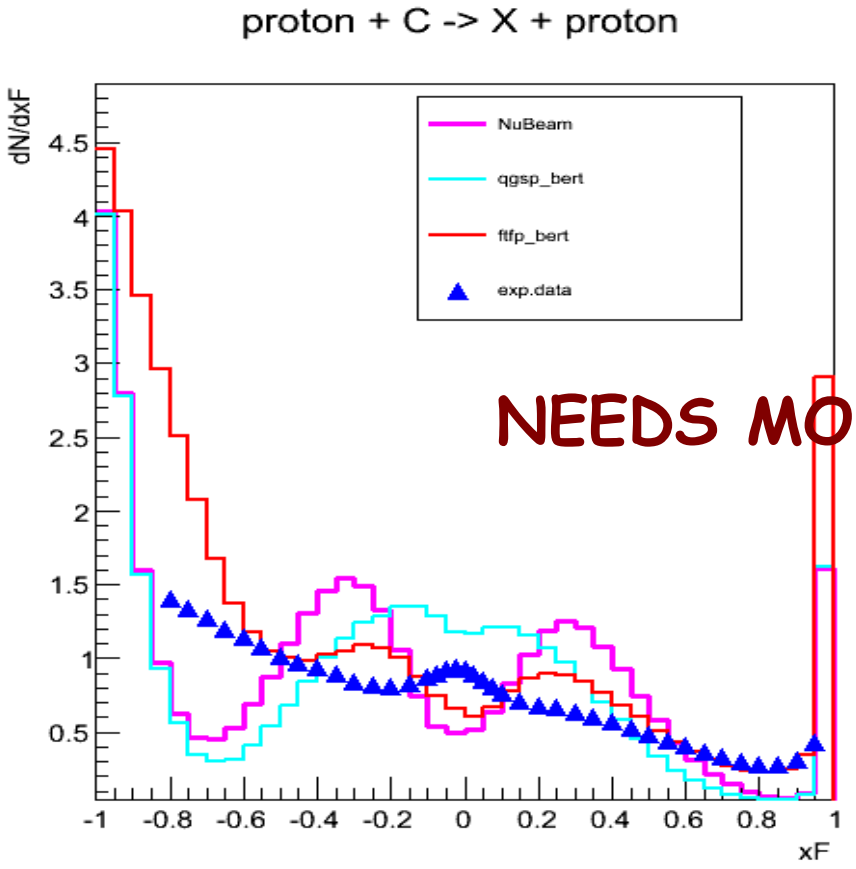


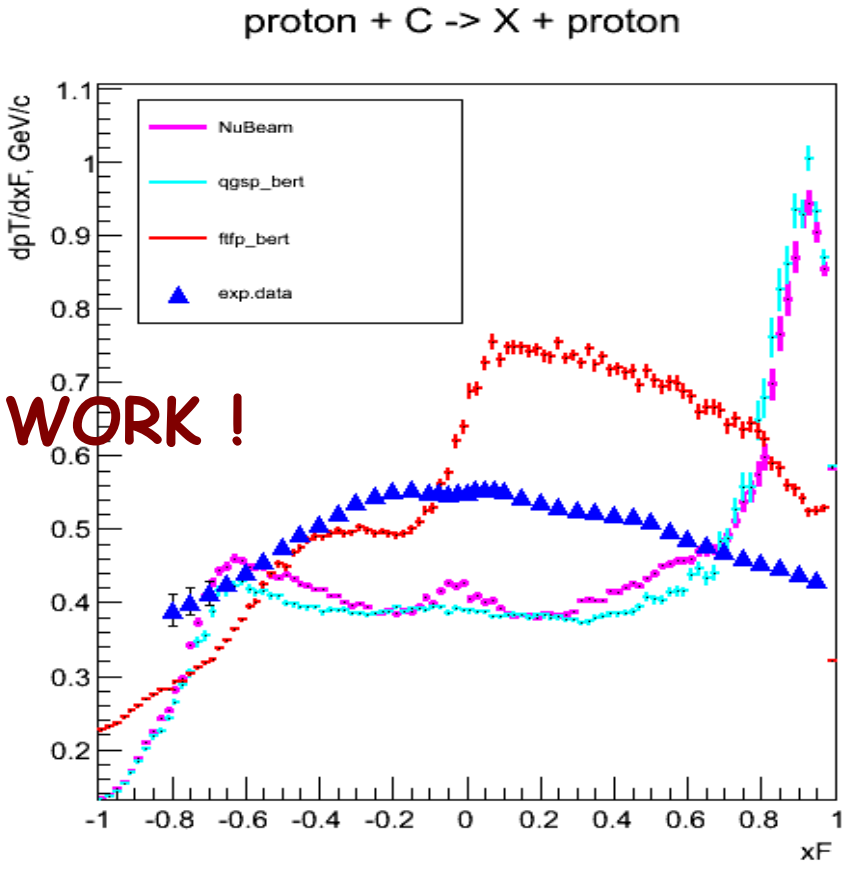


1st interaction of p on a think C target

Proton Production in p+C at 158GeV/c - Different Physics Lists

Exp.data: http://spshadrons.web.cern.ch/spshadrons/ (NA49)





NEEDS MORE WORK !

1st interaction of p on a think C target

Remarks on the HE Models Performance

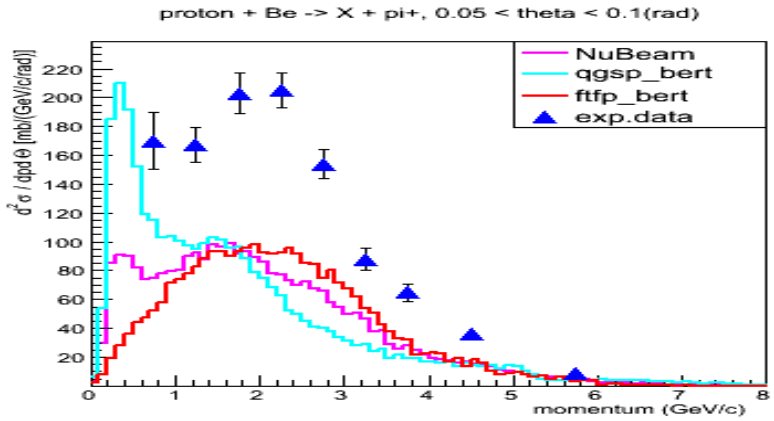
- For high energy protons (at least on C target) QGSP is a better choice that FTFP, especially if combined with G4LundStringFragmentation
- For other particle types at energies above 10GeV and up FTF is probably the best choice
- An experimental custom physics list for NuMI can be easily crafted, starting from FTFP_BERT, by small modifications/ additions
- If any weighting procedure is applied to the simulated chains, it needs to account for the fact that short-lived resonances are not immediately decayed at the "production step", but later in the processing; however they are propely included in the total simulated event

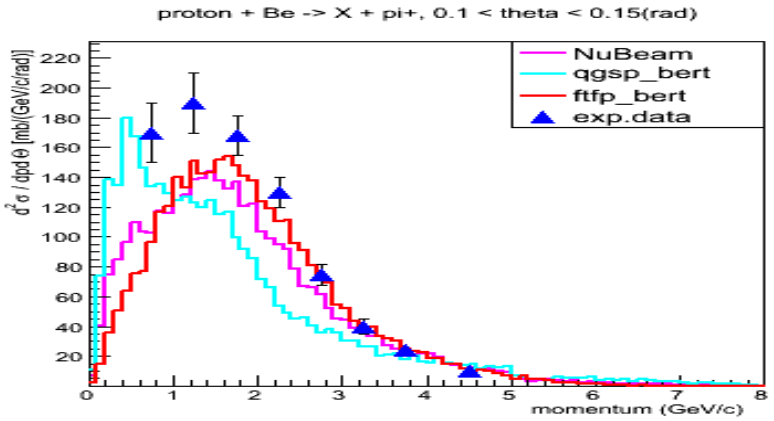
(Lower-to-)Intermediate Energy Range and Cascade Models

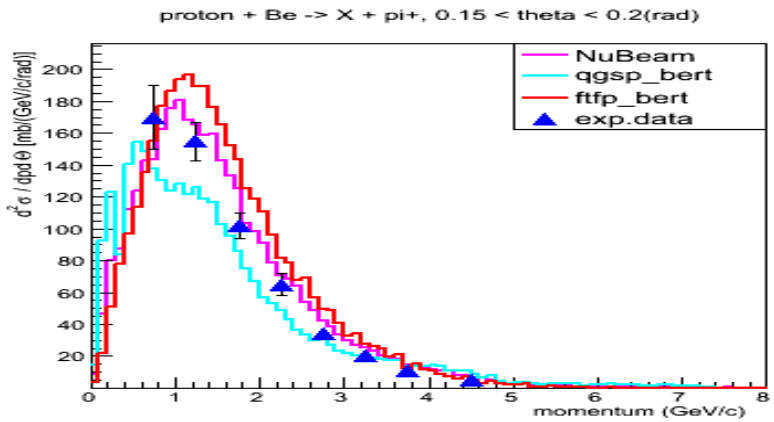
- Principle rivals: Bertini and FTF (from 3GeV up)
- Binary (up to ~3GeV) – in fact, quite good up to ~1.5GeV but very CPU expensive, not much work invested in recent times
- INCL++ - in progress
- Benchmarking/tuning datasets:
  - www-pub.iaea.org – 22MeV to 3GeV p on various targets
  - HARP & HARP-CDP – 3 to 15GeV p, pi+/- on various targets, pion and p production
  - Yu.D.Bayukov et al, Sov. J. Nucl. Phys. 42, 116 – 1.4 to 7.5GeV p, pi+/- on various targets, p and n production
- We focus on the datasets that are relevant for NuMI-X: C, Be, Al, also Ta and Cu; SUGGESTIONS WELCOME

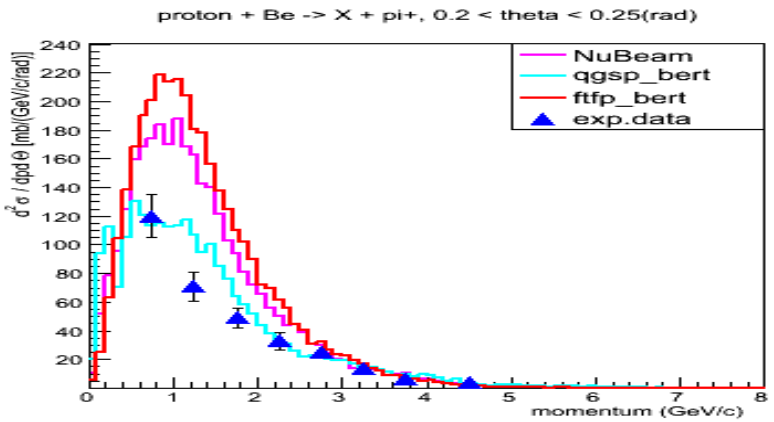
Forward Pi+ Production in p+Be at 8.9GeV/c - Different Physics Lists

HARP Exp.data: M.Appolonio et al, Phys.Rev.C82, 045208 (2010)





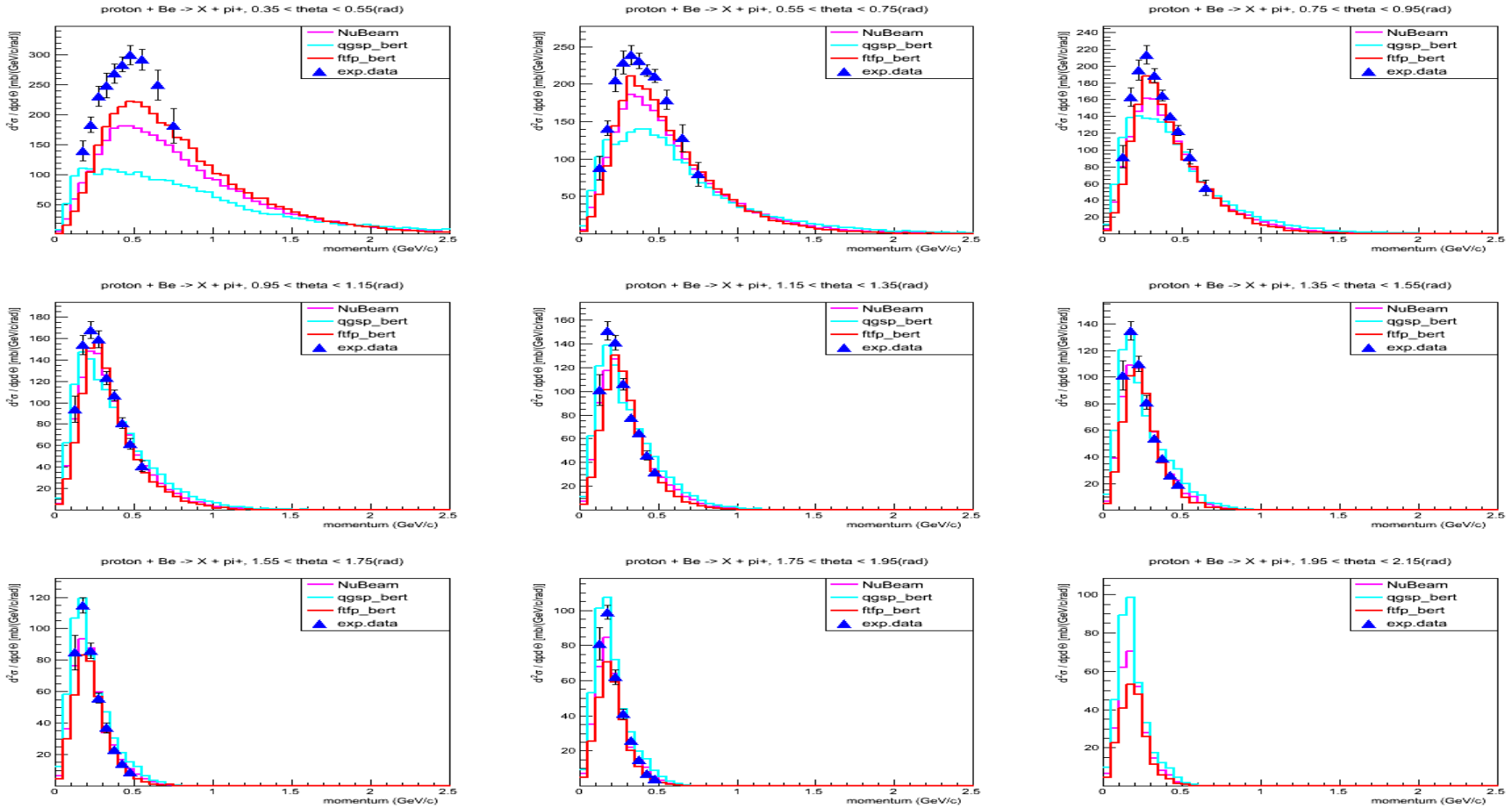




1st interaction of p on a think Be target

“Lateral” Pi+ Production in p+Be at 8.9GeV/c - Different Physics Lists

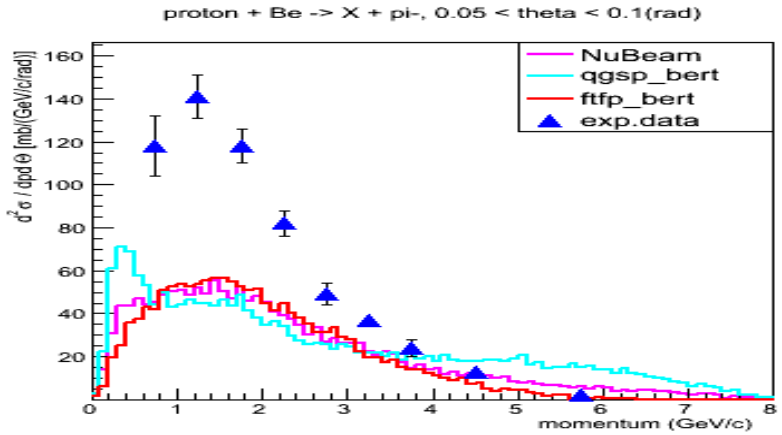
HARP Exp.data: M.Appolonio et al, Phys.Rev.C82, 045208 (2010)

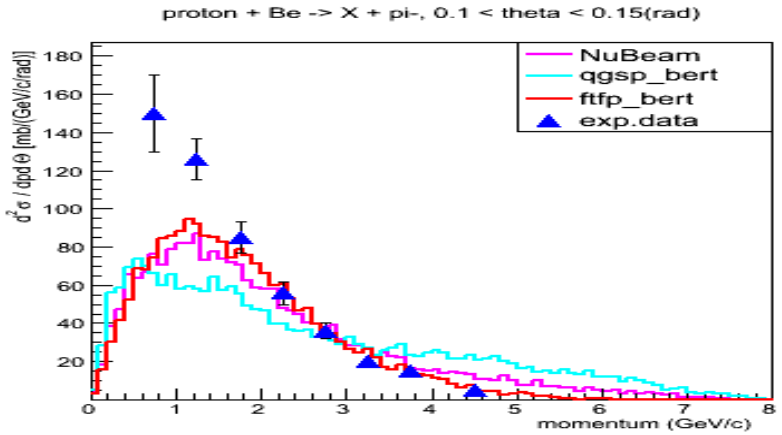


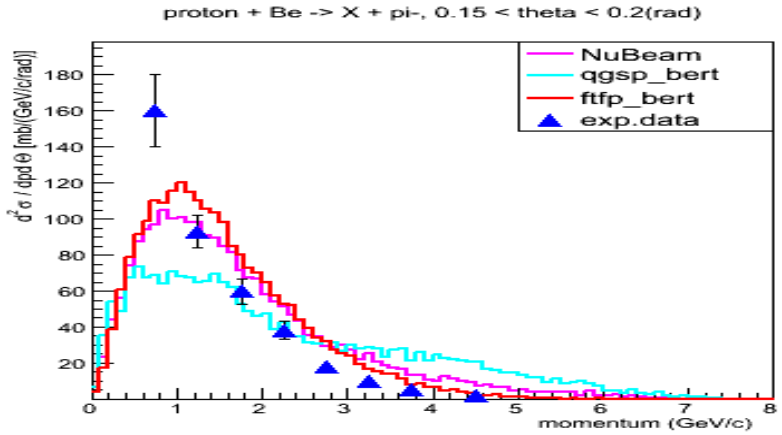
1st interaction of p on a <u>think</u> Be target

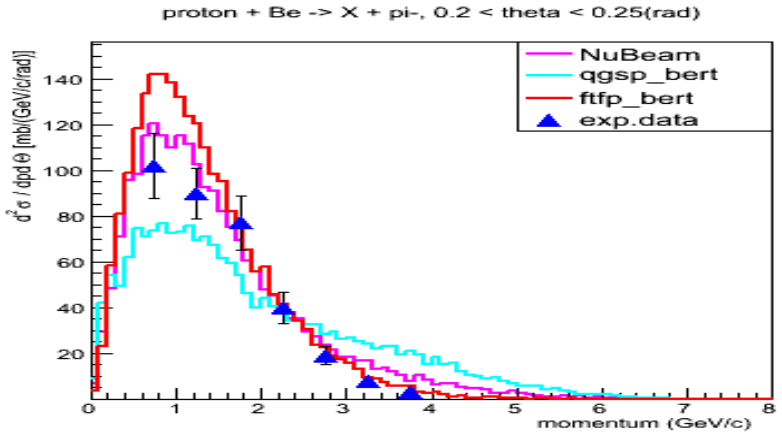
Forward Pi- Production in p+Be at 8.9GeV/c - Different Physics Lists

HARP Exp.data: M.Appolonio et al, Phys.Rev.C82, 045208 (2010)









1st interaction of p on a think Be target

“Lateral” Pi- Production in p+Be at 8.9GeV/c - Different Physics Lists

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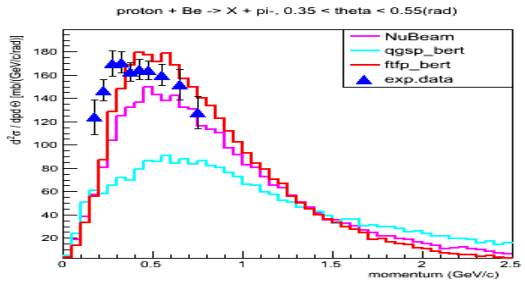

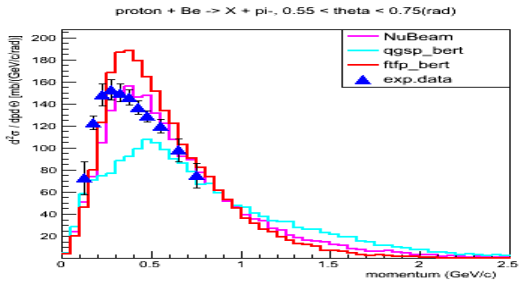

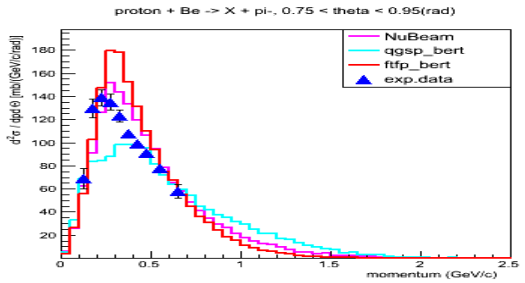

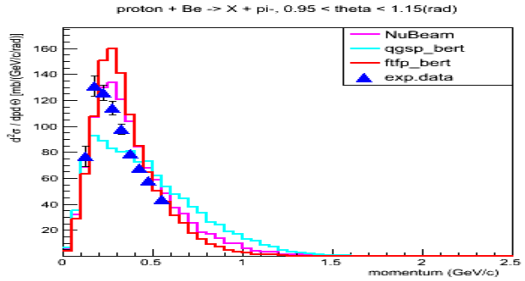

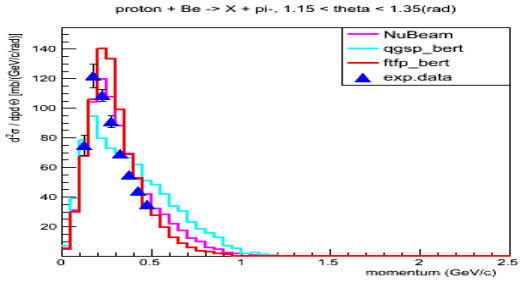

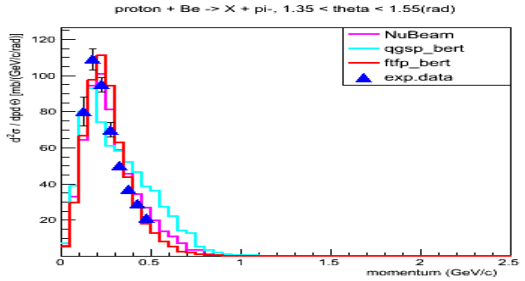

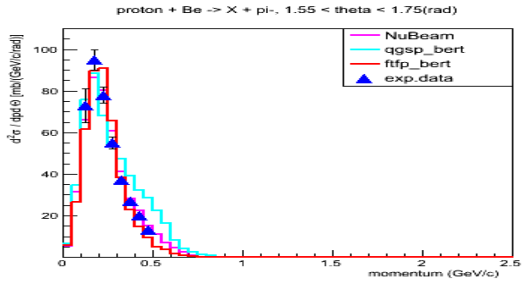

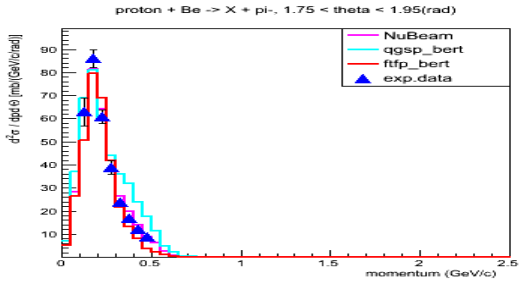

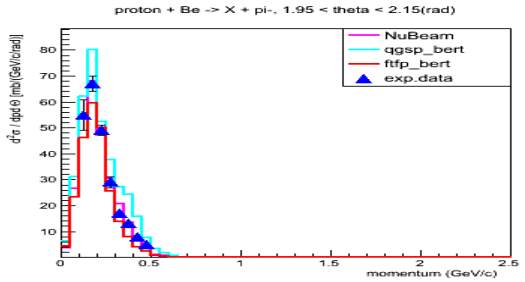

1st interaction of p on a think Be target

Remarks on Cascade Models Performance and Their Interplay at Intermediate Energies

- There're several G4 models for the intermediate energy range, but none of them is a perfect fit across fairly large collection of exp.data
- The "tuning" process, to an extent, is to find the best possible "compromise" among the combination of models and the data
- A mix of 2 models might lead to better fit of simulation with the data, than a single model, but this would be rather luck than "science"
- The best combination for a particular application is likely to be defined by specific particles and materials of importance to a project

Geant4 Validation Results

- Geant4 Validation results are available at

http://g4validation.fnal.gov:8080/G4ValidationWebApp/G4ValHAD.jsp

- Intermediate Energy Range - test30, test35, test47
- High Energy - test19
- Sorry for the jargon !!!
- Many results available for G4.9.6.p02 but not all
- We're trying to make it more user friendly; however, each group of validation plots is supplemented with reasonable annotation (models, versions, references to exp.data, etc.)

Just FYI: large collection of Geant4 hadronic validation materials is available

http://g4validation.fnal.gov:8080/G4ValidationWebApp/G4ValHAD.jsp

g4validation.fnal.gov:8080/G4ValidationWebApp/G4ValHAD.jsp

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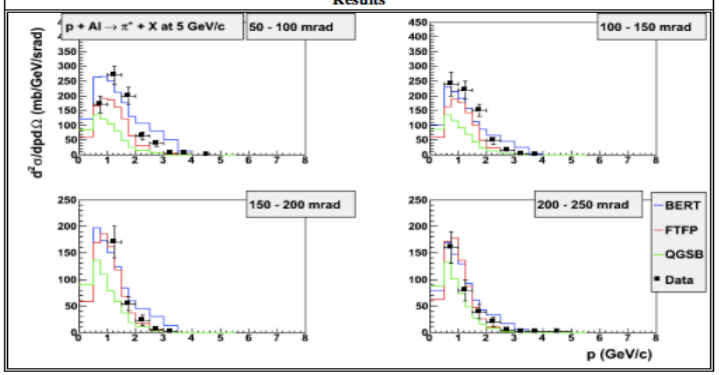
Name of the Test:	test35
Responsible:	V. Ivanchenko
Description:	Test of hadronic generators of inelastic processes, based on results of HARP collaboration, Experiment PS214 at CERN.

Geant4 Version:	geant4-09-06-ref-00
Observable:	fw_p_al_5gev
Reaction:	p + Al -> pi+ + X, 5 GeV/c, FWmodelsA
Status:	public

Test Conditions

Name	Description
Target	Al
Particle	proton
Observable	dSigma/dEdOmega
Energy	5 GeV/c
Filename	AmodelsA_pi+.gif
Upload date	Thu Dec 20 13:09:08 CET 2012
Description	Geant4 generators test on thin targets. Forward protons.
Data Source	M.Appolonio et al (the HARP collaboration), PHYSICAL REVIEW C 82, 045208 (2010)
last-modified	2012-12-30 20:20:26 CST
Score:	passed
Type:	expert

Results

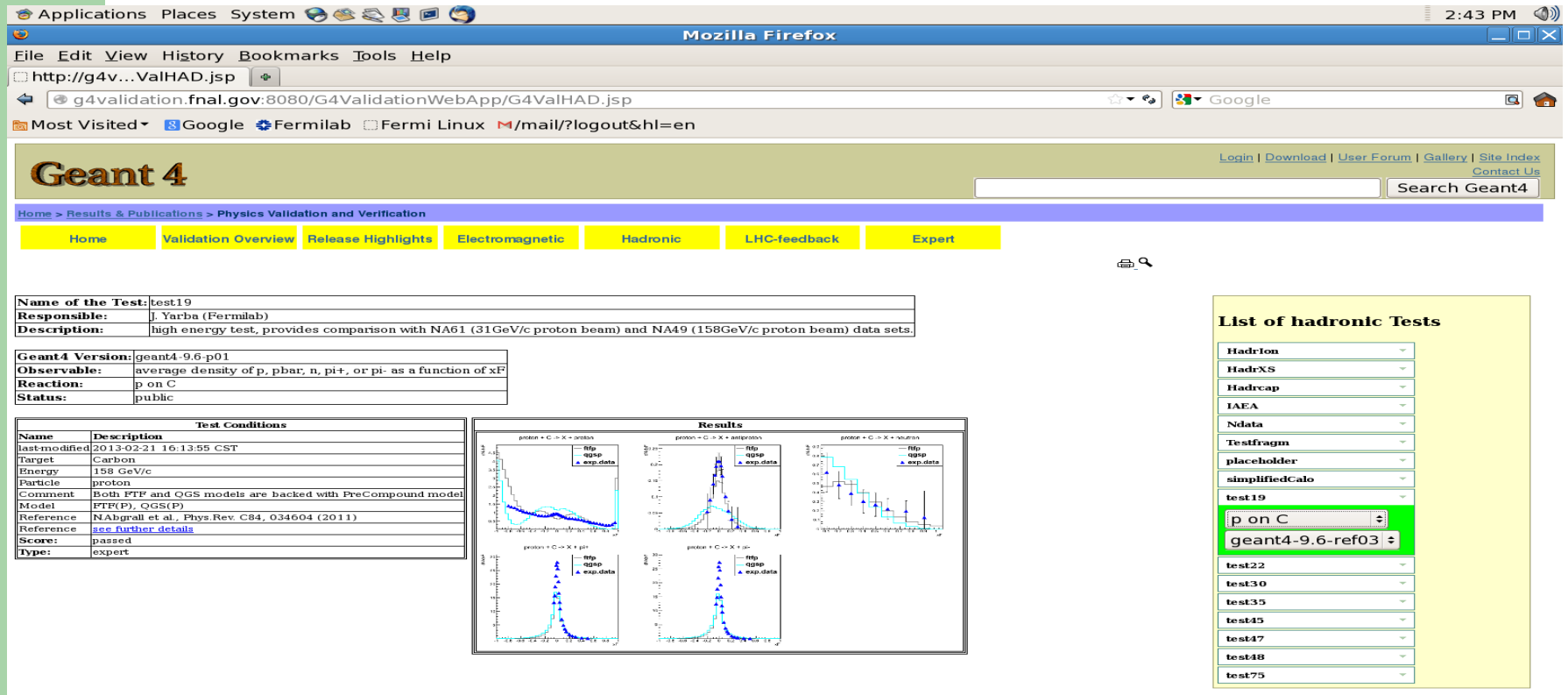


List of hadronic Tests

- HadrIon
- HadrXS
- IAEA
- Testfragm
- simplifiedCalo
- test19
- test22
- test30
- test35
  - p + Al -> pi+ + X, 5 GeV/c, FWmodelsA
  - geant4-09-06-ref-00a
- test45
- test47
- test48
- test75

Just FYI: large collection of Geant4 hadronic validation materials is available (cont.)

http://g4validation.fnal.gov:8080/G4ValidationWebApp/G4ValHAD.jsp



Geant4 Plans

- Geant4 HAD group continues its work on the models
- In particular, there're ongoing attempts to finer-tune FTF – any new thin target datasets will help
- We intent to improve and extend QGS
- Also, Geant4 is moving towards multi-threading(MT) – Geant4.10 release cycle (out in Dec.) will exhibit such features
- With regards to MT, some technicalities need to be adjusted – may affect the interface (docs)

Summary (I)

- Geant4 offers 2 options for modeling high energy hadronic interactions and several models for the lower-to-intermediate energy range
- HE models can be "customized" and/or overlaid (although a wide overlay is not practical)
- Cascade models (IE) do not have any "nobs"; combination and/or overlay depends on what particles and materials are more important
- Standard physics lists include particular combination of these, but it can be refactored

Summary (II)

- An experimental (still private) NuBeam physics lists has been composed; it re-uses most of the components as in FTFP_BERT but includes a custom proton builder and widens/shifts the FTF/BERT overlap region
- Modifications are minimal (3 classes)
- The tests are simplistic, within G4 validation
- If NuMI-X is interested to try it out and give feedback, we'll be happy to provide the list
- Work is in progress